Numerical Simulations of Episodic Mixing and Lateral Dispersion by Vortical Modes

Miles A. Sundermeyer
School for Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221
phone: (508) 999-8892   fax: (508) 910-6371   email: msundermeyer@umassd.edu

James R. Ledwell
Mail Stop # 12
Department of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-3305   fax: (508) 457-2194   e-mail: jledwell@whoi.edu

M. Pascale Lelong
Northwest Research Associates
PO Box 3027
Bellevue, WA 98009
phone: (425) 644-9660 (ext. 336)   fax: (425) 644-8422   e-mail: pascale@nwra.com

LONG-TERM GOALS

The long-term goal of this study is to gain a better understanding of the rates and mechanisms of lateral dispersion in the ocean. The specific goal of the numerical simulations in this study is to provide a quantitative basis for examining current hypotheses on the importance of lateral dispersion by vortical modes.

OBJECTIVES

This work will provide quantitative predictions, guided by observations, of rates of lateral dispersion by vortical-mode stirring over the continental shelf. A significant contribution of this work will be the direct comparison of numerical predictions to observations from the ONR-funded Coastal Mixing and Optics (CMO) experiments, as well as to theoretical results which hitherto have had only minimal observational or numerical underpinning (Sundermeyer, 1998; Sundermeyer and Ledwell, 2001). A second and major contribution of this work will be to provide a basis for parameterizing vertical and horizontal dispersion rates due to vortical-mode stirring in stratified coastal waters.

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14. ABSTRACT

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15. SUBJECT TERMS

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APPROACH

This study examines the hypothesis that lateral dispersion caused by the relaxation of diapycnal mixing events, i.e., vortical-mode stirring, may account for the observed dispersion on scales of 1 – 10 km in the ocean. Specifically, we will conduct a series of numerical experiments to study lateral dispersion associated with the generation, adjustment, and decay of vortical modes. The numerical experiments will use a three-dimensional model to solve the Navier-Stokes equations (e.g., Lelong and Dunkerton, 1998a,b), along with a simple advection/diffusion equation to solve for the evolution of a passive tracer, and an advection equation to solve for the trajectories of Lagrangian particles. The experiments will proceed in three stages. The first stage will incorporate only the simplest dynamics of stirring by geostrophicallyadjusted vortical modes. The second stage will gradually increase in complexity to include the generation and decay of vortical modes. Finally, the third stage of experiments will examine the effects of a background internal wave field, and a large-scale shear or strain field on the efficiency of vortical-mode stirring. The proposed work will thus focus on two fundamental questions regarding lateral dispersion and vortical-mode stirring:

1) What are the relative contributions of the generation, adjustment, and decay of vortical motions to lateral dispersion in the ocean?

2) How do nonlinear interactions among vortical modes, between vortical modes and the ambient internal wave field, and between vortical modes and a large-scale shear or strain field affect the efficiency of vortical-mode stirring?

The numerical simulations will be carried out by Dr. Miles Sundermeyer at the University of Massachusetts Dartmouth, and Dr. Pascale Lelong at Northwest Research Associates under a subcontract agreement. Dr. James Ledwell (Co-PI under a subcontract to the Woods Hole Oceanographic Institution) will provide data germane to the project from oceanic tracer release experiments, and will assist in the interpretation of these data in support of numerical model calibration and evaluation of model results.

WORK COMPLETED

Work on this project began in July, 2001. Thus far we have purchased and are currently configuring and installing appropriate hardware/software on a dual-processor pentium PC computer for running numerical simulations.

We have also adopted a new, fully optimized and parallelized Boussinesq code. This code, originally developed by Dr. Kraig Winters, is currently being used by Dr. Lelong and Co-PIs as part of a Department of Defense Grand Computing Challenge (see section on Related Projects). The Winters code solves the same set of equations described in our original proposal but has the advantage over the previous code of greater portability to a variety of computing platforms (pc, unix, single or multi processor architectures, etc.). This eliminates the need to rely on more than one numerical code for lower resolution simulations (done locally on a pc or workstation) and higher-resolution production runs (performed remotely on a Cray T3E at a Supercomputing Center). The ability to run on multiprocessor machines will enable us to attain much higher grid resolutions than were possible with the previous code. This will help bring us to an oceanographically relevant parameter regime.

The new code is presently being tested and modified to allow the introduction of randomly placed Gaussian-shaped density anomalies intended to represent episodic mixing events caused by a random internal wave field. Changes made to the Winters numerical code that are pertinent to lateral dispersion issues include incorporation of a Lagrangian float tracking scheme and introduction of random forcing capabilities to simulate random wave breaking events. So far, test runs have been conducted on a Cray T3E at moderate resolutions of 256x256x256, using up to 32 processors. A request for more computing allocations at DoD Supercomputing Centers is in the process of being filed.

In addition to setting up the numerical model, we have begun a retrospective analysis of the CMO dye-release experiments and microstructure observations performed by Drs. James Ledwell and Neil Oakey and colleagues. These observations are being used to estimate the time and space scales of episodic diapycnal mixing events which are believed to lead to the generation of small-scale geostrophic motions, or vortical modes. The horizontal and vertical scales of the mixing events are important in setting the spatial scales of the vortical modes. Meanwhile, the amplitudes and durations of these events set the strengths of the resultant stratification anomalies, and hence the intensity of the vortical modes.

RESULTS

In our retrospective analysis of the CMO data, we have examined spatial and temporal patterns in microstructure observations collected by Neil Oakey. By examining successive transects in a Lagrangian reference frame (i.e., by using shipboard ADCP measurements to account for water displacements and translate station locations to a common time), we have determined the degree of overlap of successive transects. This has enabled us to compare the locations and intensities of patches of high dissipation rates within these transects, from which we have determined that episodes of high turbulent dissipation rates may persist for more than 2 hours (Figure 1). This important result will allow us to estimate the change in potential energy and hence the strength of stratification anomalies associated with diapycnal mixing events. The strength and frequency of events are both important parameters for the numerical simulations.

Once we have established the time and space scales of diapycnal mixing events and their resulting stratification anomalies, we will continue with the numerical simulations as outlined in the original proposal. Specifically, we will begin by examining for a single stratification anomaly, and then for a random distribution of stratification anomalies, the spin-up and eventual decay of vortical motions and their contribution to lateral dispersion of a passive tracer. Results will be compared to observations from CMO in terms of the vertical and horizontal scales of tracer patches, and the effective vertical and horizontal diffusivities. Next, we will conduct a series of numerical experiments to examine the effects of a background internal wave field and large-scale shears and strains. These experiments will be aimed at assessing the efficiency of dispersion by vortical modes in a large-scale forcing field typical of oceanic environments. As with the base set of experiments, the large-scale forcing parameters used in the latter experiments will be guided by observations from CMO.
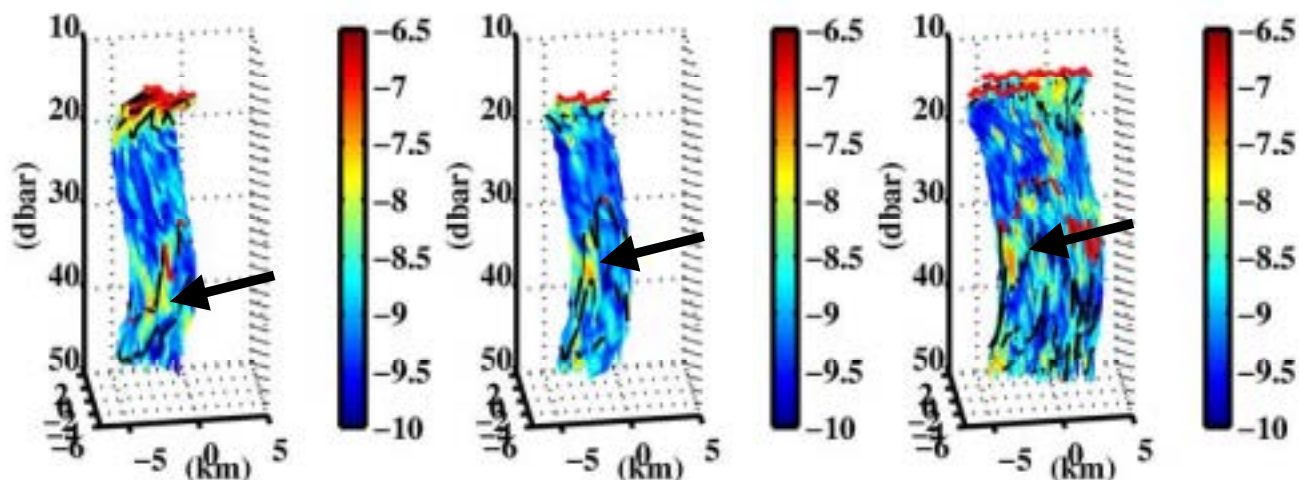
Figure 1: Three-dimensional color surface plots showing successive transects of kinetic energy dissipation rate (W/kg) computed from CMO microstructure observations by Neil Oakey. The vertical axis is pressure (dbar) and the horizontal axes are zonal and meridional distances (km) in a Lagrangian reference frame. The color indicates the magnitude of the dissipation rate, with black arrows pointing to a localized region of high dissipation rate which appears to be coherent across the three transects. Black lines overlain in each panel show potential density surfaces, with the 1025 kg/m^3 contour shown in red for reference. Note that the region of high dissipation rate moves along with the density surfaces as they vary in depth from one transect to the next. The time between successive transects is about 2 hours.

IMPACT/APPLICATIONS

The numerical experiments conducted in this study will provide a quantitative test of theoretical predictions of the rates of lateral dispersion by vortical-mode stirring (Sundermeyer, 1998; Sundermeyer and Ledwell, 2001). Specifically, we will examine the relationship between effective vertical and horizontal diffusivities, the ambient stratification, the Coriolis parameter, and the vertical and horizontal scales of diapycnal mixing events. An understanding of these relationships will be of great value to future studies, particularly the problem of parameterizing vertical and horizontal dispersion rates due to vortical-mode stirring.

TRANSITIONS

None.

RELATED PROJECTS

Observations from dye-release experiments (http://www.whoi.edu/science/AOPE/cofdl/cmodye; PI's: J. R. Ledwell and T. F. Duda) and microstructure observations (http://www.mar.dfo-

mpo.gc.ca/science/ ocean/epsonde/CMOfrm.html; PI: N. S. Oakey) conducted during the ONR-funded Coastal Mixing and Optics experiment are being used to assess time and space scales associated with diapycnal mixing events, evaluate the total mixing associated with these events, and to provide observational underpinning for numerical simulations.

In addition, a grant under the Department of Defense High Powered Computing Challenge entitled "Numerical Modeling of Wake Turbulence for Naval Applications: Vortex Dynamics and Late-Wake Turbulence in Stratification and Shear" (http://www.hpcmo.hpc.mil/Htdocs/Challenge/FY00/24.html; PI's: S. Arendt, D. P. Delisi, D. Fritts, M. P. LeLong, J. Riley, R. Robins) is part of P. Lelong's experience running highly optimized, state-of-the-art numerical models on parallel architectures such as the Cray T3E.

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